# Developmental attentional dyslexia

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Attentional dyslexia is a reading deficit in which letters migrate between neighboring words, but are correctly identified and keep their correct relative position within the word. Thus, for example, *fig tree* can be read as *fig free* or even *tie free*. This study reports on 10 Hebrew-speaking individuals with developmental attentional dyslexia and explores in detail the characteristics of their between-word errors. Each participant read 2,290 words, presented in word pairs: 845 horizontally presented word pairs, 240 vertically presented word pairs, and 60 nonword pairs. The main results are that almost all migrations preserve the relative position of the migrating letter within the word, indicating that the between-word position can be impaired while the within-word position encoding remains intact. This result is also supported by the finding that the participants did not make many letter position errors within words. Further analyses indicated that more errors occur in longer words, that most migrations occur in final letters (which are the leftmost letters in Hebrew), and that letters migrate both horizontally and vertically, and more frequently from the first to the second word in horizontal presentation. More migrations occurred when the result of migration was an existing word. Similarity within word pairs did not increase error rates, and more migrations occurred when the words shared fewer letters. The between-word errors included migration of a letter between words, intrusion of a letter from one word to the corresponding position in the neighboring word without erasing the original letter in the same position, and omission of one instance of a letter that appeared in the same position in the two words (these omissions made up a considerable percentage of the between-word errors).

## 1. Introduction

“I never do homework because I can’t even open these books. All the letters are jumping in my face,” complained TA, one of the participants in this study. Her reading of texts and even of word pairs was severely disrupted, and her main error type was migration of letters between words. However, when we suggested that she read with a word-sized window cut in a cardboard page, her mother called us, surprised, to report that she found TA reading at her leisure. Reading each word separately almost completely eliminated TA’s reading errors. This phenomenon of letters that are identified correctly but are not tied to the correct word is known as “attentional dyslexia.” This article reports the first detailed study of the types of errors and the word dimensions that affected the reading of individuals with developmental attentional dyslexia.

Attentional dyslexia is a type of peripheral dyslexia—that is, a dyslexia that results from a deficit in the early stage of orthographic-visual analysis. The visual analyzer has three distinct functions: it identifies the abstract identity of letters, it encodes their position within the word,

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and, when more than a single word is read, it sets the attentional window that allows attention to be allocated to a single word (Coltheart, 1981; Ellis, 1993; Ellis et al., 1987; Ellis and Young, 1988; Friedmann and Gvion, 2001; Humphreys et al., 1990; Peressotti and Grainger, 1995).

A deficit in each of these functions causes a different type of peripheral dyslexia, with different characteristics. A deficit in letter identity encoding results in letter substitutions and omissions (as is the case in visual dyslexia, Cuetos and Ellis, 1999; Lambon-Ralph and Ellis, 1997; Marshall and Newcombe, 1973) or in agnosia for letters and some types of neglect dyslexia. A deficit in the encoding of relative letter order within words results in transpositions of letters within the word, such as reading *tired* for *tried* and *casual* for *causal* (Friedmann and Gvion, 2001, 2005; Friedmann and Haddad-Hanna, in press; Friedmann and Rahamim, 2007). A deficit in letter-to-word binding--attentional dyslexia, which is the focus of this study--results in migrations of letters between words (Davis and Coltheart, 2002; Hall et al., 2001; Humphreys and Mayall, 2001; Mayall and Humphreys, 2002; Saffran and Coslett, 1996; Shallice and Warrington, 1977; Warrington et al., 1993).

These functions of the orthographic-visual analyzer can be selectively impaired, without impairment to the other functions. Thus, in letter position dyslexia, the letters do not keep their original position within the word, but they are identified correctly and are placed in the correct word (Friedmann and Gvion, 2001, 2005; Friedmann and Rahamim, 2007). Letter identification errors can occur without letter position errors, in visual dyslexia for example (Biran et al., 2003). In attentional dyslexia, letters migrate between words, whereas the letters’ identity and their relative position within the word are retained (Shallice and Warrington, 1977).

Shallice and Warrington (1977) were the first to report a type of acquired dyslexia that results from a deficit in selective attention, which was later termed *attentional dyslexia*. They reported on two individuals who could read single words accurately, but whose reading became substantially disrupted in the context of other words or letters, even with no time limit. Their most common error type was migration of letters from surrounding words. For example, when they were presented with the word pair *win fed*, the letter *f* from the second word migrated to the first word, and they read the word pair as *fin fed*. An important feature of such errors is that the migrating letters show a strong tendency to preserve their original within-word position in the word they intrude into. Thus, a letter migrates primarily to a corresponding position in the neighboring word, preserving its within-word position. This pattern was reported for additional individuals with acquired attentional dyslexia (Hall et al., 2001; Mayall and Humphreys, 2002; Price and Humphreys, 1993; Saffran and Coslett, 1996; Warrington et al., 1993). Shallice and Warrington (1977) also reported a related error type, intrusions, in which the migrating letter is added to the target word rather than replacing a letter in the target word. For example, when the word pair *bed woo* was presented, the letter *d* from the first word intruded into the second word, and the word pair was read *bed wood*.

Shallice and Warrington suggested that the origin of the migrations was another word presented simultaneously in the visual field or another word that was presented previously. These migrations are believed to be caused by a deficit that prevents focusing attention on one item in the context of another item or items (Shallice, 1988) and by an inability to narrow the attentional window leading to failure to suppress extraneous information (see Saffran and Coslett, 1996 for discussion). This difficulty makes it much harder to filter irrelevant letters that appear in the display.

Several characteristics of acquired attentional dyslexia have been discovered beside letter position preservation. Mayall and Humphreys (2002) reported that the left word in a word pair (in English, the first word) was more vulnerable to migration errors than the right word; that is, more letters migrated from the word presented on the right to the word presented on the left than vice versa. Saffran and Coslett (1996) found that migration errors were more frequent in low-frequency target words and in nonwords. A difficulty in reading nonwords was also reported by Hall et al. (2001). Saffran and Coslett reported, in addition, that almost no migration errors occurred when the target word pair was nonmigratable (namely, when no between-word migration created an existing word, such as the pair *town stop*).

A similar (or, at least, phenotypically similar) phenomenon of migration between words was found in normal skilled readers, in reading conditions of limited exposure time (Allport, 1977; McClelland and Mozer, 1986; Mozer, 1983; Shallice and McGill, 1978; Shetreet and Friedmann, 2009; Treisman and Souther, 1986). Allport (1977) was not primarily concerned with migration errors, but revealed that briefly presented arrays of unrelated words result in a large number of recombinations of letters from different words. Shallice and McGill (1978) replicated Allport’s findings and showed that letter migrations occurred more frequently when the original words shared letters. Mozer (1983) also presented pairs of words on a screen for brief exposure times and asked skilled readers to report only one word, according to a cue displayed after the words were presented. He found that the brief exposure produced between-word migration errors, similar to those that characterize attentional dyslexia. Mozer (1983) also found that there were more incidents of “copying” a letter from one word to the other (*fed win* → *fed fin*) than incidents of “exchanging” letters between words (*fed win* →

*wed fin*) and that more migrations occurred between words that shared letters (similarity effect). Both Mozer (1983) and Humphreys et al. (1990) reported that more migrations occurred from left to right (namely, from the first word to the second one, as they tested English). Humphreys et al. (1990) also reported that the first letter in a word tends to migrate less than the other letters, suggesting enhanced coding of first letters (Shalev et al., 2008). McClelland and Mozer (1986) found that the lexicality of the target stimuli and of the migration result affects between-word migrations, as more migrations occurred between nonwords than between words, especially when the outcome was a real word. The same type of lexical effect was also reported by Treisman and Souther (1986).

Not much is known about attentional dyslexia in its developmental form. The only previously documented case of developmental attentional dyslexia was reported by Rayner et al. (1989), who described an individual who read single words better than text, and whose reading improved significantly when he used a 7- to 15-letter-sized window while reading. However, Rayner et al. only reported data on reading speed. The types of errors made in developmental attentional dyslexia, the characteristics of these errors, and the factors that affect reading in developmental attentional dyslexia are yet to be systematically explored.

In the current study, we explore the nature of developmental attentional dyslexia. We start by presenting the participants with developmental attentional dyslexia and demonstrating the existence of developmental attentional dyslexia. We then describe the types and rates of various between-word errors in the participants' reading. We next explore the characteristics of their reading and compare them with those known from the literature on acquired attentional dyslexia and on normal reading in brief exposure conditions.

## 2. Participants

### *2.1. Initial screening*

To select individuals with developmental attentional dyslexia for this study, we tested the reading of individuals with developmental reading disorders. They had difficulties with reading, were identified as having learning disabilities and reading difficulties, or were suspected to have such deficits. However, the exact nature of their reading difficulties and the type of dyslexia had not been identified, and they were referred to our lab by special education teachers, by speech therapists, or by their parents for further diagnosis.

For the initial assessment and identification of individuals with developmental attentional dyslexia, we used the TILTAN test battery (Friedmann and Gvion, 2003), which was developed to identify subtypes of dyslexia. The screening part of the TILTAN uses oral reading of 128 single words, 30 word pairs, and 60 nonword pairs. The word and nonword pairs are constructed such that between-word migrations create other existing words, to enable the detection of between-word migrations, and hence, of attentional dyslexia. The word list includes words of various types that can reveal the different types of dyslexia: irregular words, homophones, and potentiophones,[1] for identifying surface dyslexia; words (and nonwords) that can be read as other words by neglecting one side of the word, for identifying neglect dyslexia; words with many orthographic neighbors, for identifying visual dyslexia; abstract words and function words , for identifying deep dyslexia; morphologically complex words, for identifying deep dyslexia and other types of dyslexia; and migratable words (and nonwords), for identifying letter position dyslexia. The nonwords are included for identifying phonological and deep dyslexia, as well as various peripheral dyslexias.

For each individual, we analyzed the types of errors made in oral reading. We included in the study only individuals who made between-word migration errors on more than 20% of the word pairs in the screening task (unimpaired readers make fewer than 3% errors of this type in the TILTAN screening test). Each of the participants with attentional dyslexia also made significantly more between-word migrations than the control group, as verified by Crawford and Howell’s (1998) *t*-test.

### *2.2. Selected participants’ profile*

Using this procedure, we selected 10 participants who made a high rate of migration errors between words. They were 9 children and adolescents aged 10;0–15;0 and one adult aged 62, 4 females and 6 males. Table 1 presents background information on the participants. In all cases, the dyslexia was developmental: 9 of the participants had no history of brain lesion, neurological disease, or loss of consciousness. NI had a different history; he reported a developmental dyslexia that involved “letters jumping between words,” and he later sustained a left frontal infarct (4 months before the current study). This brain area is not known to cause peripheral dyslexias, and NI reported that the stroke did not affect his reading; hence, it is likely that the attentional dyslexia was developmental in his case too. Two of the participants, TA and IF, were diagnosed with attentional disorders prior to the study and were not treated with methylphenidate at the time of testing. One of the participants, YO, also had

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[1] We use the term *potentiophones* for pairs of words that are written differently and sound different, but when read aloud via the grapheme-to-phoneme conversion route each can be substituted for the other. A relevant example in English is the word *now*, which when read via the sublexical route might be uttered as *no* or *knows* (Friedmann and Lukov, 2008).

developmental graphemic buffer dysgraphia (for details on his writing pattern, see Yachini and Friedmann, 2009).

**Table 1 - Background information on the participants with attentional dyslexia**

| Participant | Age | Grade | Gender | Class type | Additional details |
|---|---|---|---|---|---|
| YA | 10;6 | 5 | female | regular | |
| TA | 12;6 | 6 | female | regular | diagnosed with ADD |
| IF | 11;3 | 5 | male | regular | diagnosed with ADHD |
| NI | 62;5 | - | male | - | left frontal infarct |
| IT | 10;0 | 4 | male | regular | |
| YO | 15;0 | 9 | male | regular | has graphemic buffer dysgraphia; receives corrective teaching |
| AV | 10;1 | 4 | male | regular | |
| TW | 10;6 | 4 | female | regular | receives corrective teaching |
| GY | 10;7 | 4 | male | regular | |
| NO | 11;6 | 6 | female | regular | |

The results of the TILTAN screening test (summarized in Table 2) for these participants indicated that they all had a considerable rate of between-word migrations (in 20% to 37% of the word pairs). Most of them also made errors that indicate reading via the grapheme-to-phoneme conversion route rather than via the lexical route, that is, surface dyslexia-like errors. Grapheme-to-phoneme conversion reading is typical of developmental dyslexia of various types (and has also been reported for developmental letter position dyslexia, Friedmann and Rahamim, 2007, and for developmental neglect dyslexia, neglexia, Friedmann and Nachman-Katz, 2004). These errors result, we believe, from avoidance of reading – our participants expressed frustration with and deep dislike of any activity that involved reading, and refrained from it as much as they could. This, in turn, hinders the establishment of an orthographic input lexicon and forces reading via the sublexical route. The tendency to read via the sublexical route is frequently the most notable difference between the acquired and developmental manifestations of the same dyslexia: acquired peripheral dyslexias are usually free of errors that result from reading via the sublexical route, but developmental peripheral dyslexias are frequently accompanied by such errors (see Friedmann and Gvion, 2002). The lack of words in the orthographic input lexicon is especially problematic in Hebrew, and becomes very evident in reading Hebrew: no Hebrew word can be read unambiguously solely on the basis of grapheme-to-phoneme conversion, because of the underspecification of vowels and stress, and the ambiguity in conversion to phonemes of most of the letters.

Because these errors are not at the core of developmental attentional dyslexia, but rather result from lack of practice with reading, in the following analyses we disregarded these errors, so that when a word was read by grapheme-to-phoneme conversion but without any between-word error, we counted it as correct.

No errors typical of deep dyslexia (semantic or morphological errors) or phonological dyslexia (morphological or voicing errors, see Gvion and Friedmann, in press) were detected. The participants' reading of nonwords also indicated that none of them had phonological or deep dyslexia, as the main type of error in their reading of nonwords was between-word errors, which occurred in 8%–87% of the nonwords, with an average of 35% (between-word errors were all errors that resulted from a letter in a neighboring word, including letter migrations, letter insertions, and letter deletions, as will be described in detail in 4.1). In Section 4.2 we will analyze the participants' letter position errors and show that within-word migrations occurred significantly less frequently than between-word migrations; in section 4.4, we will analyze the participants' letter identity errors (substitutions, omissions, and additions) in detail, and show that their identity errors mostly result from the attentional deficit in reading.

**Table 2 – Percentage of errors of the various types in the screening reading test**

| Participant | Between-word migration | Surface dyslexia | Voicing errors | Semantic errors |
|---|---|---|---|---|
| YA | 33 | 22 | - | - |
| TA | 28 | 34 | - | - |
| IF | 23 | 29 | - | - |
| NI | 37 | 5 | - | - |
| IT | 20 | 13 | - | - |
| YO | 37 | 22 | 1 | - |
| AV | 23 | 10 | - | - |
| TW | 20 | 16 | - | - |
| GY | 33 | 25 | - | - |
| NO | 33 | 16 | 1 | - |
| **Control** | **3** | **4** | **-** | **-** |

The control group included 10 participants without reading or language disabilities and without any known neurological impairment. They were 7 girls and 3 boys, aged 9;10–10;10, who attended the 4th grade.

## 3. General method

*Material*

To assess the rates and types of errors individuals with developmental attentional dyslexia make, and to explore the properties of stimuli that affect their reading, we asked the participants to read aloud 725 word pairs, presented in 11 booklets. These 725 pairs included 24 types of word pairs (30 each of 23 types and 35 of one other type). Each of the 24 types is presented and exemplified in Table 3. Each page of the booklets included two words, presented side by side, with a single keyboard space between them. The words were printed in font David 14. The words ranged in frequency between 1 and 455 occurrences per million, with an average of 44.5 (frequencies taken from Frost and Plaut, 2005), and the different conditions were balanced with respect to frequency: there was no significant difference between the frequencies of the 3-, 4-, and 5-letter words, between the frequencies of the word pairs of same and different lengths, or between the frequencies of the migratable and nonmigratable word pairs ($p > .50$ for each of these comparisons). There was also no significant difference between the frequencies of the left-hand and right-hand members of each word pair ($p = .22$).

To allow testing for length effect, the list included three-, four-, and five-letter word pairs. There were 150 three-letter word pairs, 300 four-letter word pairs, and 150 five-letter word pairs. All of these word pairs were *migratable* (i.e., a migration between the words in each pair could create other existing words) and included words of the same length. To allow comparison of word pairs that share one or two letters in various positions in the various lengths, these word pairs were constructed as shown in the first 20 lines in Table 3.

Thirty additional 4-letter word pairs were constructed so that intrusion would create existing words, to allow the detection of *intrusions*, that is, errors in which a letter from the neighboring word intrudes and is added next to the letter that is in the same position in the target word (e.g., when the letter *l* from the second word in *fight light* intrudes into the first word, the result is *flight light*), and *elbowing* errors, in which the intrusion as described above also causes the final letter to be omitted (e.g., when the letter *a* from the first word in *late left* intrudes into the second word and elbows out the final letter *t*, the result is *late leaf*). The 30 word pairs for this assessment were pairs in which an intrusion or elbowing error would yield an existing word.

**Table 3 - Types of word pairs in the 725 word pair list, 30 pairs of each type were presented**

| | | Target pair | | | Possible migration | | |
|---|---|---|---|---|---|---|---|
| | Different letter | Hebrew | Transliteration | Translation | Hebrew | Transliteration | Translation |
| **3 letters** | 1 | קוף סוף | kof sof | monkey end | סוף סוף | sof sof | end end |
| | 2 | קמה קנה | Kmh Knh | woke-up bought | קנה קמה | knh kmh | bought woke-up |
| | 3 | גשם גשר | gSm gSr | rain bridge | גשם גשם | gSm gSm | rain rain |
| | 1,3 | מגן דגל | mgn dgl | shield flag | מגל דגן | mgl dgn | sickle cereal |
| | 2,3 | רעש רגל | rʔS rgl | noise leg | רגש רעל | rgS rʔl | emotion poison |
| **4 letters** | 1 | מתוח פתוח | mtox ptox | stretched open | פתוח פתוח | ptox ptox | open open |
| | 2 | ילדה ירדה | Ildh irdh | girl descended | ירדה ילדה | irdh ildh | descended girl |
| | 3 | מילה מיטה | milh miTh | word bed | מיטה מיטה | miTh miTh | bed bed |
| | 4 | מחבת מחבר | mxbt mxbr | pan connects | מחבר מחבת | mxbr mxbt | connects pan |
| | 1,2 | גלים קרים | glim krim | waves cold | גרים קלים | grim klim | live light |
| | 1,3 | עופר חומר | ʔopr xomr | dear material | עומר חופר | ʔomr xopr | sheaf digs |
| | 1,4 | חולה עולם | xolh ʔolm | ill world | עולה חולם | ʔolh xolm | ascend dreams |
| | 2,3 | מעקה מנסה | mʔKh mnsh | railing tries | מנקה מעסה | mnkh mʔsh | cleans massages |
| | 2,4 | שימן שומר | Simn Somr | oiled keeps | שומן שימר | Somn Simr | grease preserved |
| | 3,4 | גוזל גורם | gozl gorm | chick cause | גורל גוזם | gorl gozm | fate prunes |
| **5 letters** | 1 | מגירה סגירה | mgirh sgirh | drawer closure | סגירה מגירה | sgirh mgirh | closure drawer |
| | 3 | תרגיל תרמיל | trgil trmil | exercise satchel | תרמיל תרגיל | trmil trgil | satchel exercise |
| | 5 | סיפוק סיפון | sipok sipon | satisfaction deck | סיפון סיפון | sipon sipon | deck deck |
| | 1,5 | טיפוח קיפול | Tipox kipol | fostering fold | קיפוח טיפול | kipox Tipol | discrimination treatment |
| | 3,5 | נמלים נמשיך | nmlim nmSiK | ants continue | נמשים נמליך | nmSim nmliK | freckles crown |
| Intrusion/Elbowing | | קורא מחבת | kora mxbt | reads pan | קורא מחברת | kora mxbrt | reads notebook |
| Different length migratable[1] | | חוק שד | xok Sd | law demon | חוק שק | xok Sk | law sack |
| Same length migratable no shared letter | | חלה שוב | xlh Sob | got-sick again | חלב שוב | xlb Sob | milk again |
| Same length nonmigratable | | סגול חתול | sgol xtol | purple cat | - | | |

[1] There were 35 words of this type

To test whether between-word migrations preserve the within-word relative or linear position, we included 30 additional word pairs, each pair consisting of words that differ in length, for which both a linear-position-preserving migration and a relative-position-preserving migration yield a real word. For example, for the word pair *me ball*, a migration that preserves the relative (final) position of the letter *e* yields *me bale*, and a migration preserving its linear (second) position yields *me bell*.

To explore whether more errors occur between words of the same length than between words of different lengths, the list also included 30 migratable word pairs whose words were the same length and 30 migratable word pairs whose words differed in length. The words in each of these word pairs shared no common letters. Twenty-five of the different-length pairs were used for the linear/relative analysis.

To assess the effect of lexicality of response on the error rate--namely, whether more errors occur when the between-word migration yields a real word than when it yields a nonword--we included 30 four-letter nonmigratable word pairs that differed in two letters, for which none of the migrations could yield an existing word ("same length nonmigratable" in Table 3). These words were compared with the 180 four-letter migratable word pairs that also differed in two letters.

These 725 word pairs were the basis for all the analyses below (Sections 4.1–4.12). For the comparison of horizontal and vertical migrations in Section 4.7, we added 240 vertically presented pairs, separated by 1, 3, or 10 spaces, and 120 horizontally presented pairs in which the words in each pair were separated by 3 or 10 spaces; for the analysis of nonword reading, we added 60 nonword pairs presented in Section 4.10 and 4.11. The design of these additional stimuli is reported in the relevant sections.

### *Procedure*

The participants read the words aloud, all the sessions were recorded fully on a digital recorder, and the participants' responses were transcribed during the session. After each session, two or three of the experimenters (the authors) listened to the recorded responses again, and transcribed the responses fully. The agreement between these transcriptions was very high. Cases of disagreement were settled by listening again to the recording and using the notes taken during the session.

### *Statistical analyses*

Within-participant comparisons of performance in two conditions were conducted using a chi-square test; comparisons between conditions at the group level were conducted using the Wilcoxon signed-rank test (results reported with *T*, the minimum sum of ranks). Crawford and Howell's (1998) significance *t*-test was used to compare the performance of each of the experimental participants with the performance of the control group. The performance of the attentional dyslexia group was compared with the performance of the control group using the

Mann-Whitney test. The only parametric test we used was a linear contrast to assess length effect at the group level.

## 4. Experimental investigation

### *4.1. Establishing the attentional dyslexia of the participants and the existence of developmental attentional dyslexia: error rate and error types*

The first findings of this research are that developmental attentional dyslexia exists and that it involves migrations of letters between words, as reported for adults with acquired attentional dyslexia. This section assesses the rate and types of between-word errors made by the participants with developmental attentional dyslexia.

As Table 4 shows, the average rate of between-word errors in reading the list of 725 word pairs (described in Table 3) was 29%. Two of the participants even made such errors on more than half of the target pairs. Each of the participants with developmental attentional dyslexia made significantly more between-word errors than the control group of 4th graders, $p < .006$. At the group level, too, the group with developmental attentional dyslexia made significantly more between-word errors than the control group, U = 100, $p < .0001$.

**Table 4 – Percentage of between-word errors out of the 725 word pairs made by each of the participants with developmental attentional dyslexia**

| | YA | TA | IF | NI | IT | YO | AV | TW | GY | NO | **Average** | Control (SD) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Migration | 5.1 | 6.3 | 4.4 | 12.1 | 3.6 | 13.2 | 3.6 | 3.2 | 6.5 | 13.9 | **7.2** | 2.2 (0.9) |
| Buffer migration | 3.3 | 4.7 | 3.2 | 5.4 | 9.4 | 12.3 | 1.7 | 4.6 | 6.8 | 7.4 | **5.9** | 0.2 (0.2) |
| Omission of doubled letter | 4.4 | 6.5 | 8.3 | 11.4 | 21.1 | 19.4 | 2.3 | 10.5 | 10.3 | 30.2 | **12.4** | 1.0 (0.7) |
| Intrusion | 1.9 | 1.2 | 2.0 | 4.2 | 5.2 | 6.5 | 1.7 | 3.9 | 6.4 | 5.4 | **3.8** | 0.7 (0.5) |
| **Total between-word errors** | **14.7** | **18.7** | **17.9** | **33.1** | **39.3** | **51.4** | **9.3** | **22.2** | **30.0** | **56.9** | **29.3** | **4 (1.6)** |

The between-word errors were of four types. Table 4 presents the percentages of the various types of between-word errors per participant. The first, *between-word migration*, is the classic error type reported for attentional dyslexia: substitution of one letter by a letter from a neighboring word. For example, if the target word pair is *mild file*, a between-word migration of *m* from the first to the second word would yield the response *mild mile*.

A second error, which we termed *buffer migration*, is the same as the classic migration between words, except that the migrating letter comes from a word previously presented, rather than from a word in the visual field. Although the previous word is no longer present in the visual field, it probably still exists in some visual buffer. For example, if the word pair *mild file* is presented after the word *wind* was presented, a buffer migration of the letter *w* from *wind* would yield *wild file*.

A third error type, which turned out to be very frequent, was *omission of a doubled letter*, that is, omission of one instance of a letter that appeared in the same position in both words. For example, *sport spell,* in which *p* appears in the same position in the two words, can be read as *sort spell* or *sport sell* if one instance of the doubled letter is omitted. Omitting an instance of a doubled letter is a frequent error in the reading of individuals with letter position dyslexia, which is characterized by within-word migrations that result from a deficit in the encoding of letter position within words. In letter position dyslexia, the doubled letter appears twice in the same word. This omission was explained by Friedmann and Rahamim (2007) using Gottfried Wilhelm Leibniz's principle of *Identity of Indiscernibles* (Leibniz, 1680-1684/1969; see also 1714/1898). This principle determines that if two objects have all properties in common, then they are identical; namely, they are one. To account for the omission of an instance of a doubled letter *within* a word, if we take letters to be objects, and position in the word to be a property, when a letter appears twice in a word, the abstract identity of the two letters does not differ, but they do have different position properties and therefore we know they are not identical. However, when the mechanism of position encoding within a word is impaired, the reader loses the only property that distinguishes between the two letters and therefore might take them to be identical, a single letter, reading *drivers* as *divers* or *drives,* for example. The same rationale holds for between-word position impairment in attentional dyslexia. If a letter appears in the same position in two adjacent words (such as *p* in *sport* and *spell*), an individual who has problems ascribing a letter to the right word would not always know that the letter appeared twice, because the identity of the letter and its position within the word are identical, and the only distinctive feature, its ascription to a word, is missing. As a result, the two letters might be taken as identical, that is – as one letter. This in turn might cause one instance of the letter to be omitted.

Finally, a fourth, less frequent between-word error was *intrusion.* Intrusion errors are migrations in which the migrating letter does not substitute for a letter in the same position, but is added next to it. For example, intrusion of the letter *l* from the first to the second word in the word pair *real word* would yield *real world.* A subtype of the intrusion error, which accounted for 10.2% of the intrusions, is the *elbowing* error. These errors are intrusion errors in that a letter adds itself next to an existing letter in the same position rather than replacing it. However, the elbowing letters intrude more aggressively, "pushing," as it were, the other letters toward the end of the word and causing the final letter to fall off (e.g., if the pair *fleece feet* is presented, and the letter *l* intrudes into the word *feet* and elbows out the final letter *t*, the pair will be read *fleece flee*).

### *4.2. Can between-word migrations occur without within-word migrations?* (*In other words, can attentional dyslexia exist without letter position dyslexia?*)

Both letter position dyslexia and attentional dyslexia result from an orthographic-attentional deficit, the former at the word level, the latter at a level above the single word. The errors are similar: both involve migrations. However, in letter position dyslexia these migrations take place within a word, and in attentional dyslexia they take place between words. Some articles that have described individuals with attentional dyslexia reported deficits on both the word and above-word levels (Hall et al., 2001; Humphreys and Mayall, 2001; Price and Humphreys, 1993; Shallice and Warrington, 1977; Warrington et al., 1993)– when a letter is surrounded with other letters and when a word is surrounded with other words. In the current study, we test whether the participants with developmental attentional dyslexia, who make between-word migrations, also make within-word migrations, in order to find out whether attentional dyslexia is possible without similar difficulties at the word level. This analysis, which encompassed the between-word migrations (from the neighboring word or from the buffer) and within-word migrations that each participant made in reading the 725 word pairs (described in Table 3), indicated that the group made significantly more between-word migrations than within-word migrations, T = 1, $p$ = .002. At the individual level, 7 of the participants made significantly more between-word migrations than within-word migrations (see Table 5; darker cells indicate significantly more between-word errors than matching within-word errors).

We compared not only migration errors but also omissions. When we compared omissions that are between-word errors with omissions that are within-word errors, again the pattern of more between word errors emerged. The group with developmental attentional dyslexia omitted significantly more letters that appeared at the same position in both words (9%) than letters that appeared twice in the same word (3%), T = 0, $p$ = .001. This was statistically significant for 3 of the participants and marginally significant for another one.

We also compared the rate of within-word migrations the participants made with the rate made by two other groups: individuals with developmental letter position dyslexia, and control participants without reading disorders (both groups reported by Friedmann and Rahamim, 2007). Each of the participants with developmental attentional dyslexia made significantly fewer middle letter position migrations within words than the individuals with letter position dyslexia, $t(10) > 1.81$, $p < .05$, and none of the participants made significantly more within-word migrations than the control group, $t(10) < 1.03$, $p > .33$.

As shown in Section 4.5, the distribution of errors across positions is also different between the two dyslexias: whereas in letter position dyslexia the middle letters are most susceptible to within-word position errors, in attentional dyslexia the final letters are more susceptible to between-word migrations.

**Table 5 – Percentage of between- and within-word migrations**

| | YA | TA | IF | NI | IT | YO | AV | TW | GY | NO | Average |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Migration | | | | | | | | | | | |
| between words | 6.3 | 9.8 | 5.5 | 11.9 | 5.9 | 18.2 | 4.6 | 4.0 | 13.3 | 16.1 | **9.6** |
| within words | 1.6 | 1.4 | 4.0 | 4.1 | 4.6 | 1.5 | 1.6 | 4.1 | 3.3 | 3.7 | **3.0** |
| Doubled letter omission | | | | | | | | | | | |
| between words | 2.3 | 4.8 | 7.4 | 7.5 | 17.9 | 13.2 | 1.4 | 8.2 | 7.6 | 22.0 | **9.2** |
| within words | 1.6 | 3.1 | 3.1 | 2.1 | 1.6 | 1.6 | 0.0 | 1.6 | 4.7 | 9.4 | **2.9** |

### *4.3. Do between-word migrations preserve within-word position?*

If indeed the participants do not have a deficit in the encoding of letter positions within the word, as indicated by the results of the previous section, letters that migrate between words should keep their original within-word position. Shallice and Warrington (1977), in their pioneering study on attentional dyslexia, discovered that letters migrate primarily to corresponding positions in the other word, preserving their within-word positions (this was also found by Price and Humphreys, 1993; Saffran and Coslett, 1996; and Warrington, Cipolotti, and McNeil, 1993).

#### *4.3.1 Position preservation in same-length pairs*

To test whether the between-word errors of the participants with developmental attentional dyslexia in the current study also preserve within-word position, we classified their between-word migrations into migrations that preserve the exact within-word position and those that do not. These between-word migrations were taken from the migratable word pairs of the same length, 150 three-letter word pairs, 300 four-letter word pairs, and 150 five-letter word pairs.

#### *Results*

The results, presented in Table 6, are very clear: 94% of the between-word migrations preserve the original within-word position (as shown in the rightmost column of the table); and as a group, the participants with developmental attentional dyslexia made significantly more position-preserving errors than non-position-preserving errors in each of the three word lengths. Each individual participant showed the same tendency for position-preserving between-word migrations, and almost all of these individual comparisons were statistically significant. Notice that the chance rate for position preserving migration is in fact 1/4, namely, a letter from one word can migrate to either one of four positions in the other word, only one of which is in the same position. Thus, the fact that there were actually more position preserving migrations than non-position preserving migrations is even more impressive, with position-preserving migrations occurring significantly more frequently than chance, $t(9) = 42.52$, $p < .0001$.

**Table 6 – Percentage of between-word migrations that preserve or do not preserve the within-word position of the migrating letter. (Percentage of the total number of words presented for each length)**

| | 3-letter words | | | 4-letter words | | | 5-letter words | | | % preserving |
|---|---|---|---|---|---|---|---|---|---|---|
| Participant | preserve | no | $\chi^2$ | preserve | no | $\chi^2$ | preserve | no | $\chi^2$ | |
| YA | 7 | 1 | 7.64** | 4 | 0 | 8.5*** | 5 | 0 | 7.17** | 94% |
| TA | 5 | 2 | 2.36 | 3 | 0 | 10.17*** | 9 | 1 | 11.86*** | 85% |
| IF | 4 | 1 | 3.66^ | 3 | 0 | 7.5** | 4 | 0 | 6.12* | 92% |
| NI | 8 | 0 | 7.28** | 10 | 1 | 16.63*** | 18 | 3 | 11.94*** | 90% |
| IT | 3 | 0 | 5.08* | 3 | 0 | 9.14*** | 6 | 0 | 9.28*** | 100% |
| YO | 11 | 1 | 15.13*** | 10 | 1 | 25.88*** | 17 | 1 | 25.44*** | 93% |
| AV | 1 | 0 | 2.01 | 2 | 0 | 4.56* | 8 | 0 | 12.5*** | 100% |
| TW | 3 | 0 | 4.05* | 4 | 0 | 9.51*** | 3 | 0 | 4.05* | 100% |
| GY | 5 | 1 | 2.86 | 7 | 0 | 21.76*** | 7 | 0 | 11.42*** | 95% |
| NO | 7 | 0 | 11.42*** | 16 | 3 | 31.51*** | 9 | 1 | 11.86*** | 89% |
| **Average** | **5.3%** | **0.6%** | T= 0, *p*= .002 | **6.2%** | **0.6%** | T= 0, *p*= .002 | **8.3%** | **0.4%** | T= 0, *p*= .002 | **94%** |

^$p < .1$, *$p < .05$, **$p < .01$, ***$p < .001$

*4.3.2. Do between-word errors preserve relative or linear position?*

Whereas it is clear what “same position within the word” means when a letter migrates between words of the same length, the definition of “same position” for words of different lengths is not trivial. For example, given the word pair *be lift*, will a position-preserving migration of the letter *e*, which is the second but also the final letter in the first word, cause it to migrate according to its linear position (i.e., to the second position) or according to its position relative to the end of the word (i.e., to the final position)? If the position is encoded linearly, the result will be *be left*; if it is relative, it will be *be life*.

The findings of this assessment can shed light on the way within-word positions are encoded – whether they are encoded relative to the exterior letters (the final letter according to Humphreys et al., 1990, or the first and final letters according to Peressotti and Grainger, 1995, 1999) or encoded according to their linear position, irrespective of their position relative to the first and final letters.

To assess this question, we created a list of 30 word pairs that included words of different lengths (see Table 3); the shorter word in each pair was 2–3 letters long and the longer word was 3–5 letters long. The final letter of the shorter word could either migrate to the final position in the other word and create an existing word, or migrate to its linear position in the other word (second or third position) and create a different existing word.

### *Results*

The total number of final-letter migrations from the shorter word for all the participants was 35. Of these 35 errors, 83% (29 errors) preserved the relative position, and only 17% preserved the linear position. This difference was significant, $\chi^2 = 30.23$, $p < .0001$, and this pattern was significant for 3 of the participants. These results support the notion of relative letter position encoding.

## *4.4. Do these errors really come from neighboring words?*

To find out whether the errors that we classified as between-word errors – migrations, buffer migrations, omissions of doubled letters, and intrusions--really do originate in the neighboring word or whether they instead involve random letters that simply happen to also occur in the neighboring word, we compared the observed rate of such errors that could be explained by a letter from the neighboring word with the rate expected by chance. We did this analysis for substitutions (migrations and buffer migrations), additions (intrusions), and omissions (omissions of doubled letters). Because there are 22 letters in the Hebrew alphabet, the expected rate of a letter being replaced by a specific letter (the letter that exists in the same position in the other word) would be 1/21 (because the target letter itself will not cause an error), namely, less than 5%. This is the expected rate with which the substitution/omission/addition of letters that existed in the same position in the neighboring word was compared.

### *4.4.1. Do substitutions really result from migrations from the neighboring word?*

We classified errors of substitution by a letter that appears in the same position in the other presented word as between-word migrations. To quantitatively estimate whether these were indeed between-word migrations or just random substitutions with a letter that happened to occupy the same position in the neighboring word, we compared the rate of substitutions with a letter that existed in the other word with the expected rate of 4.76%. We found that substitutions with a letter from a neighboring word in the same position constituted 85% of the substitutions,[2] a rate significantly higher than expected by chance, $\chi^2 = 930.93$, $p < .0001$. This finding indicates that the participants' substitution errors indeed resulted from migration of a letter from the neighboring word and can be counted as between-word migrations. The participants did not make many substitutions that were not accounted for by their attentional dyslexia: there were significantly more substitutions with a letter from the neighboring word than with a letter that was not in the neighborhood, both for each individual participant and for the group, as shown in Table 7.[3]

**Table 7 – Number of substitutions with a letter that did or did not exist in the neighboring word**

| Participant | In the neighboring word | Not in the neighboring word | $\chi^2$ |
|---|---|---|---|
| YA | 43 | 4 | 64.72*** |
| TA | 71 | 18 | 63.12*** |
| IF | 32 | 7 | 32.05*** |
| NI | 58 | 12 | 60.46*** |
| IT | 43 | 16 | 24.71*** |
| YO | 129 | 27 | 133.38*** |
| AV | 33 | 5 | 41.26*** |
| TW | 29 | 2 | 47.03*** |
| GY | 57 | 10 | 65.94*** |
| NO | 117 | 12 | 170.93*** |
| **Total** | **612 (85%)** | **113 (15%)** | T = 0, *p* = .002 |

****p* < .001

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[2] Here and in all the following tables that include numbers per participant and average percentage, the average is calculated as the average of the percentage per participant (which is slightly different from the percentage of the summary because NI read 481 word pairs instead of 725).

[3] Notice, that substitutions with a letter from the other word outnumbered other substitutions even though in Hebrew there many options for a substitution with a random letter that is not in the other word: each of the 4-letter words had around 10 orthographic neighbors – words that are created by a substitution of a single letter, and the 3-letter words even had around 30 neighbors each. Against the background of this very dense orthographic neighborhood in Hebrew, still the substitutions were predominantly with a letter that appeared in the neighboring word.

### *4.4.2. Do buffer migrations really result from migrations from the previous word?*

When a letter migrated from a word that was presented right before the target word, but no longer appeared in the reader's visual field, we termed the error a *buffer migration*, suggesting that the substituting letter arrived from a previously presented word that had not yet cleared the buffer. To test whether this was indeed the case, we used the same logic we used in the previous section for migrations from a word in the visual field: we compared the number of migrations (substitutions and additions) that could be accounted for by migration from the previously presented word with the rate expected by chance. This analysis included the substitutions and additions that did not originate in the same position in the neighboring word (reported in Sections 4.4.1 and 4.4.3); therefore, the rate expected by chance was 1/20 (rather than 1/21 in the previous analysis, because the letter that appeared in the same position in the other word was not included in this count).

As another measure of the probability that a migration would involve a letter that happened by chance to exist in the previously presented word—that is, as a measure of random distribution of letters--we compared the number of migrations that could be accounted for exclusively by a migration from the previously presented word (namely, letters that existed in the previous word but not in the next word) with the number of migrations that could be accounted for exclusively by a letter in the next word (which has not been presented yet).

### *Results*

The results of comparing migrations that could come from the previously presented word with the expected rate of such errors, presented in the first column of Table 8, were unequivocal: the migrations indeed came from the previously read word, as indicated by the high rate of substitutions/additions of a letter that existed in the same position in the previous word, which no longer exists in the visual field. The participants made 87% such migrations from the buffer, a rate significantly higher than the rate expected by chance, $\chi^2 = 525.17$, $p < .0001$.

The other type of analysis, presented in the rightmost columns of Table 8, indicated that significantly more migrations could be explained exclusively as arriving from the previous word than from the next word, a difference that was significant both at the group level and for each individual participant except AV, who had a relatively low migration rate.

**Table 8 – Percentage of migrations that could be accounted for by the previously presented word, and number of migrations that could be explained exclusively by the previous or the next word**

| Participant | % migrations from previous word | Number of migrations exclusively explained by | | |
|---|---|---|---|---|
| | | previous word | next word | before-after |
| YA | 91% | 13 | 3 | 8.1*** |
| TA | 100% | 16 | 0 | 22.1*** |
| IF | 100% | 10 | 0 | 12.74*** |
| NI | 100% | 8 | 0 | 9.45*** |
| IT | 83% | 30 | 15 | 6.69** |
| YO | 81% | 41 | 20 | 10.23*** |
| AV | 81% | 5 | 3 | 0.67 |
| TW | 83% | 17 | 7 | 5.83* |
| GY | 100% | 9 | 0 | 16.36*** |
| NO | 81% | 10 | 3 | 6.35** |
| **Average** | **87%** | **46%** | **10%** | T = 0, *p* = .002 |

**p* < .05, ***p* < .01, ****p* < .001

A question that immediately arises concerns the type of buffer from which the letters migrate: is it an orthographic or a phonemic buffer? Luckily, Hebrew allows a direct examination of this question. In Hebrew, several letters are mapped onto more than one sound. For example, ש can be read as /s/ or /sh/, פ as /f/ or /p/. We thus analyzed the cases in which these ambi-phoneme letters migrated, and we found that out of 87 such cases, 19 could only be explained as migration from an orthographic buffer: they involved migration of a letter that was pronounced one way in the previous word, migrated graphemically, and was pronounced differently in the new word. This means that what migrates is a graphemic, rather than phonemic, representation of the letter that appeared in the previous word.

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### *4.4.3. Do intrusions really come from the neighboring word?*

A very similar rationale holds for evaluating the source of intrusions. The comparison of the rate of additions of a letter that occurred in the neighboring word with the expected rate of additions of a random letter indicated that the source of the intrusions was indeed the neighboring word: 72% of the additions involved letters that existed in the neighboring word, a rate significantly higher than the rate expected by chance, $\chi^2 = 578.64$, $p < .0001$.

As shown in Table 9, at the group level the number of intrusions from a neighboring word was significantly larger than the number of added letters that did not exist in the other word for the group; it was also significantly larger for 8 of the individual participants and marginally significantly larger for one other.

**Table 9 – The number of intrusions that can and cannot stem from the neighboring word**

| Participant | From the neighboring word | Not from the neighboring word | $\chi^2$ |
|---|---|---|---|
| YA | 29 | 1 | 52.27*** |
| TA | 17 | 6 | 10.52*** |
| IF | 29 | 20 | 3.31^ |
| NI | 38 | 17 | 12.3*** |
| IT | 86 | 22 | 75.85*** |
| YO | 98 | 30 | 69.14*** |
| AV | 17 | 5 | 13.09*** |
| TW | 53 | 8 | 66.39*** |
| GY | 39 | 26 | 5.2* |
| NO | 33 | 43 | 2.63 |
| **Total** | **439 (72%)** | **178** | T = 1, $p = .002$ |

^$p < .1$, *$p < .05$, ***$p < .001$

### *4.4.4. Do omissions of doubled letters happen because two identical letters occur in the same position in neighboring words?*

We classified the omission of one instance of a letter that appears in the same position in the two words as an attentional error – namely, an error related to the deficit in ascribing letters to words (see Section 4.1). To assess whether letter omissions in the target word indeed mainly happened because an identical letter existed in the same position in the neighboring word, or whether they were just random omissions, we treated omissions in a manner similar to substitutions and additions.

To establish that these were indeed omissions of a doubled letter rather than random omissions, we compared the number of omissions of a single letter that existed in the same position in the other word with the number of omissions of letters that appeared in only one of the words. This analysis included the 630 words that shared letters and hence had the potential for both omission of a doubled letter and omission of a letter that appeared in only one of the words.

*Results*

As seen in Table 10, the participants significantly more often omitted a letter that appeared in the same position in both presented words than a letter that appeared in only one of the words: on average, 81% of the total number of omissions involved omitting an instance of a doubled letter. This result was significant for each of the participants and for the group. This indicates that the omissions really resulted from a deficit in ascribing a letter to a word.

**Table 10 - The number of omissions of a letter that appears in the same position in both words compared with omissions of a letter that appears in only one of the words**

| Participant | Omission of a doubled letter | Omission of a single letter | $\chi^2$ |
|---|---|---|---|
| YA | 15 | 0 | 15.18*** |
| TA | 43 | 7 | 26.99*** |
| IF | 51 | 27 | 7.87** |
| NI | 31 | 8 | 14.00*** |
| IT | 112 | 33 | 48.64*** |
| YO | 77 | 23 | 31.67*** |
| AV | 9 | 1 | 6.45** |
| TW | 54 | 21 | 15.44*** |
| GY | 71 | 18 | 33.96*** |
| NO | 195 | 47 | 112.03*** |
| **Total** | **658 (81%)** | **185** | T = 0, *p* = .002 |

***p* < .01, ****p* < .001

During the analysis of between-word errors, we detected a type of error that we contend is also related to the between-word deficit. In addition to the 658 simple omissions of a letter that appeared in the same position in both words, in 146 word pairs one instance of a letter that appeared in both words was omitted, and another letter took its place. In 75% of these cases, this filler letter was a letter that existed in the other presented word or in the previously presented word; that is, significantly more often the omitted doubled letter was replaced with a letter that appeared in the neighboring words than with a letter that did not appear in the neighboring words. In addition, in 57 word pairs a doubled letter was omitted from one word and then another letter from the other word migrated to a different position and elbowed the other letters to fill the gap caused by the omission. (A relevant English example is the word-pair *long bond*. In this pair, *n* appears in both words in the same within-word position. If the *n* is omitted from the first word, the sequence *lo_g* is created, and then the letter *b* from the second word migrates to the beginning of the first word and elbows the other letters toward the gap, creating *blog*.)

Thus, the analyses of the participants' substitutions, omissions, and additions indicate that the source of these errors was the neighboring words.

### *4.5. Which positions are most sensitive to between-word migrations?*

In at least two other peripheral dyslexias, certain positions in the word are more susceptible to errors than others. Individuals with neglect dyslexia fail to identify the letters at one side of the word, typically the left side (Costello and Warrington, 1987; Haywood and Coltheart, 2001; Patterson and Wilson, 1990; Savazzi, 2003). In Hebrew, which is written from right to left, a left neglect dyslexia leads to neglect of the ends of words (Friedmann and Nachman-Katz, 2004; Nachman-Katz and Friedmann, 2007). In letter position dyslexia, the middle letters are more sensitive to letter position errors, whereas the exterior letters are relatively error-free (Friedmann, Dotan, and Rahamim, in press; Friedmann and Gvion, 2001, 2005; Friedmann and Haddad-Hanna, in press; Friedmann and Rahamim, 2007). We were interested in finding out whether in attentional dyslexia there are specific positions in the word that are more susceptible to between-word migration errors, and if so, which ones.

A study of attentional dyslexia by Mayall and Humphreys (2002) indicated that their English-speaking participant, FL, had considerable difficulty with the beginning (i.e., left side) of words. However, FL also showed signs of mild left neglect dyslexia in single-word reading, and therefore it is not clear whether his elevated error rate on the left side was a result of his attentional dyslexia or his neglect dyslexia. In contrast, studies of normal reading in English indicated that the first letter, which is the leftmost letter in English, is less susceptible to between-word migration, whereas the final (rightmost) letter is the one that migrates the most (Mozer, 1983).

It is thus interesting to find out if there are certain within-word positions that are more susceptible to between-word errors, and if so, whether the vulnerability of leftmost letters reported for FL holds also for individuals with developmental attentional dyslexia who do not have neglect dyslexia in single-word reading, or whether, like normal readers, individuals with developmental attentional dyslexia have a tendency toward final- or rightmost-letter migrations. Because Hebrew is read from right to left, it is also interesting to see whether such sensitivity, if found, relates to the right side of the word (the beginning) or to the left side (the end).

To assess this question, we used the 725 word pairs presented in the booklets (described in Table 3). For each position, we counted the number of migrations of the letter in this position and divided it by the number of words in which migrations of this letter could be detected. For example, for the word pair *house mouse* only the migration of the first letter could be detected.

The 725 word pairs include 344 pairs with a potential for first-letter migration, 503 pairs with a potential for middle-letter migration, and 406 pairs with a potential for final- letter migration.

*Results*

The results, presented in Table 11, show a very clear difference between the various positions: the final (leftmost) letter migrated significantly more frequently than the letters in the first (rightmost) and middle positions. No significant difference was detected between the first and middle positions.

**Table 11 - Percentage of between-word migrations of first, middle, and final letters**

| Participant | First | Middle | Final | First-middle | Middle-final | First-final |
|---|---|---|---|---|---|---|
| YA | 2 | 1 | 4 | 3.62^ | 14.66*** | 3.32^ |
| TA | 1 | 1 | 6 | 0 | 17.59*** | 13.63*** |
| IF | 1 | 0 | 5 | 2.93 | 25.34*** | 12.35*** |
| NI | 6 | 4 | 10 | 1.06 | 9.31*** | 3.28^ |
| IT | 1 | 1 | 3 | 0.2 | 5.31* | 5.58* |
| YO | 2 | 3 | 13 | 0.72 | 30.62*** | 28.92*** |
| AV | 0 | 1 | 4 | 0.41 | 13.46*** | 12.07*** |
| TW | 1 | 1 | 3 | 0.01 | 7.09** | 4.84* |
| GY | 1 | 2 | 7 | 1.78 | 17.74*** | 20.23*** |
| NO | 3 | 5 | 8 | 1.64 | 3.24^ | 7.72* |
| **Average** | **2%** | **2%** | **6%** | T = 24, *p* = .77 | T = 0, *p* = .002 | T = 0, *p* = .002 |

^*p* < .1, **p* < .05, ***p* < .01, ****p* < .001

These data from Hebrew shed light on the source of previous results from English (normal reading under short exposure conditions) showing that participants made more errors in rightmost letters, which are final letters in English. Is it a tendency to err in the final letters or in the rightmost letters? Because in Hebrew, which is read from right to left, most of the errors occurred in the final, leftmost letters, we can conclude that the tendency is for the final letter to migrate, rather than the rightmost letter.

### *4.6. Is there a length effect on between-word migrations?*

Because the deficit in attentional dyslexia is attentional in nature, it is possible that more stimuli in the visual field yield more errors, and hence that longer words yield more between-word errors. In fact, increased error rate as a function of increased word length has been found for some individuals with neglect dyslexia, which is also an attention-based dyslexia (Baxter and Warrington, 1983; Caramazza and Hillis, 1990; Cubelli and Simoncini, 1997;

Kinsbourne and Warrington, 1962; Ladavas et al., 1997; Savazzi, 2003; Subbiah and Caramazza, 2000; Takeda and Sugishita, 1995; Warrington, 1991). However, some other studies on neglect dyslexia found better performance on longer words (Costello and Warrington, 1987; Patterson and Wilson, 1990) or no length effect (Arduino et al., 2005; Ellis et al., 1987; Haywood and Coltheart, 2001; Miceli and Capasso, 2001; Worthington, 1996).

We thus tested the effect of word length on the rate of between-word errors in developmental attentional dyslexia. To assess this question, we used word pairs that included words of the same length with one or two different letters from the booklets described in Table 3 (the 3-, 4-, and 5-letter pairs). There were 150 three-letter word pairs, 300 four-letter word pairs, and 150 five-letter word pairs. For each length, we calculated the number of between-word attentional errors (including migrations, buffer migrations, omissions of a doubled letter, and intrusions) and the number of pure between-word migrations out of the number of word pairs of this length.

### *Results*

The results, presented in Table 12, indicate a clear length effect on both between-word migrations and between-word errors. Longer words yielded more between-word errors.

Preplanned (a priori) trend analyses for linear contrasts for the length effect yielded a significant linear contrast both for the between-word errors, $F(1,9) = 5.50$, $p = .04$, and for the between-word migrations, $F(1,9) = 15.47$, $p = .003$, indicating a constant increase in the number of between-word errors and migrations as a function of the number of letters.

The effect of length is significant beyond the number of letters that can migrate. The separate analysis of word pairs in the different lengths that differ in the same number of letters yielded 15%, 23%, and 35% migrations for the 3-, 4-, and 5-letter words that differed in one letter, and 29%, 29%, and 47% for the 3-, 4-, and 5-letter words that differed in two letters. Thus, keeping the number of letters that can migrate constant, the word’s length still affects the rate of migrations.

**Table 12 - Percentage of between-word errors and between word migrations in word pairs of different lengths**

| Participant | 3 letter | 4 letter | 5 letter | Comparison 3-4 letters | Comparison 4-5 letters | Comparison 3-5 letters |
|---|---|---|---|---|---|---|
| Between-word errors | | | | | | |
| YA | 16 | 16 | 12 | 0 | 1.27 | 0.99 |
| TA | 19 | 13 | 26 | 2.53 | 11.79 *** | 2.32 |
| IF | 15 | 17 | 25 | 0 | 4.77 * | 4.63 * |
| NI | 20 | 30 | 47 | 3.38^ | 8.9 *** | 16.29 *** |
| IT | 26 | 35 | 60 | 3.72^ | 25.45 *** | 35.37 *** |
| YO | 39 | 46 | 59 | 1.63 | 6.76 ** | 11.21 *** |
| AV | 7 | 8 | 16 | 0.39 | 6.06 * | 6.5 * |
| TW | 11 | 21 | 33 | 6.77** | 7.61 ** | 20.92 *** |
| GY | 23 | 30 | 39 | 2.69 | 3.4^ | 9.03 *** |
| NO | 33 | 52 | 83 | 15.58*** | 39.23 *** | 76.8 *** |
| **Average** | **21%** | **27%** | **40%** | T = 3, *p* = .01 | T = 1, *p* = .002 | T = 1, *p* = .002 |
| Between-word migrations | | | | | | |
| YA | 7 | 4 | 5 | 2.29 | 0.11 | 0.95 |
| TA | 7 | 3 | 10 | 3.60^ | 8.47 *** | 0.67 |
| IF | 5 | 4 | 4 | 0.26 | 0.03 | 0.08 |
| NI | 8 | 11 | 21 | 0.91 | 4.87 * | 6.6 ** |
| IT | 3 | 3 | 6 | 0.04 | 2.34 | 1.20 |
| YO | 12 | 11 | 18 | 0.18 | 4.72 * | 2.12 |
| AV | 1 | 3 | 8 | 0.82 | 6.7 ** | 7.5 ** |
| TW | 3 | 4 | 3 | 0.76 | 0.76 | 0.00 |
| GY | 6 | 7 | 7 | 0.16 | 0.02 | 0.21 |
| NO | 7 | 19 | 10 | 0.14 *** | 5.65 ¯* | 0.67 |
| **Average** | **6%** | **7%** | **9%** | T = 19.5, *p* = .37 | T = 8.5, *p* = .1 | T = 4.5, *p* = .01 |

^*p* < .1, **p* < .05, ***p* < .01, ****p* < .001

Longer words with the same number of different letters include more common letters and hence might be more liable to omission of doubled letters. And indeed, an analysis of these errors indicated a marked increase in the number of omissions of doubled letters when the word length increased: when the words in the word pair differed in a single letter, the 3-, 4-, and 5-letter pairs yielded an average of 2%, 9%, and 22% omissions of doubled letters, respectively. A similar result was obtained for the word pairs that differed in two letters: the 3-, 4-, and 5-letter pairs yielded an average of 1%, 8%, and 18% omissions of doubled letters, respectively. This increased omission rate might be the main source of the length effect in attentional dyslexia.

### *4.7. Are there errors in both horizontal and vertical presentation?*

Most reports of attentional dyslexia describe horizontal migrations. Do migrations also occur vertically, and if so, are the characteristics of vertical migrations similar to those of horizontal migrations? We made three comparisons between horizontally and vertically presented word pairs, with 1, 3, or 10 spaces between the words. The horizontal space sizes were 1, 3, and 10 mm; the vertical space sizes were 3, 13, and 46 mm. The word pairs in each of these six conditions (horizontal/vertical × 1/3/10 spaces) were migratable, differed in two letters, and included 3-, 4-, and 5-letter words of the same length. All six conditions included the same distribution of word pairs with respect to word length and the position of the two shared letters.

The horizontally presented single-spaced word pairs were 425 pairs, taken from the general word pair booklets (described in Table 3) according to the criteria described above. The vertically presented single-spaced word pairs were 120 pairs (3 of the participants read only 86 of these vertical word pairs, and 3 read 60). The other four lists of word pairs (horizontal/vertical × 3/10 spaces) included 60 word pairs each. The stimuli in each of these six conditions were presented in separate booklets, with one word pair per page.

#### *Results*

As shown in Table 13, migrations between words and between-word errors in general occurred at similar rates between horizontally and vertically presented words. No significant difference was found between these rates at the group level, and no individual showed consistently more errors in one of the presentation directions.

These results indicate that between-word errors occur in both horizontal and vertical presentation. The results also show a decrease in error rate when the words are separated by larger spaces--in particular in the horizontal presentation, between one and three spaces. (Findings regarding the effect that spacing and other manipulations of the presented word pairs had on the reading of these participants are detailed in Shvimer, Kerbel, and Friedmann, 2009.)

**Table 13 – Percentage of errors between words in horizontal and vertical presentations**

| | 1 space | | | 3 spaces | | | 10 spaces | | |
|---|---|---|---|---|---|---|---|---|---|
| Participant | horizontal | vertical | $\chi^2$ | horizontal | vertical | $\chi^2$ | horizontal | vertical | $\chi^2$ |
| Between-word errors | | | | | | | | | |
| YA | 13 | 15 | 0.24 | 10 | 13 | 0.32 | 13 | 12 | 0.08 |
| TA | 20 | 28 | 2.69^ | 17 | 17 | 0 | 17 | 18 | 0.06 |
| IF | 19 | 12 | 3.36^ | 13 | 28 | 4.09* | 20 | 12 | 1.56 |
| NI | 39 | 27 | 3.08^ | 20 | 10 | 1.18 | 27 | 13 | 1.67 |
| IT | 37 | 20 | 3.38^ | | | | | | |
| YO | 56 | 58 | 0.1 | | | | | | |
| AV | 10 | 12 | 0.12 | 7 | 7 | 0 | 13 | 22 | 1.44 |
| TW | 24 | 42 | 8.22*** | 32 | 32 | 0 | 32 | 32 | 0 |
| GY | 32 | 28 | 0.69 | 22 | 28 | 0.71 | 17 | 10 | 1.15 |
| NO | 58 | 60 | 0.2 | 42 | 75 | 13.71*** | 45 | 70 | 7.67** |
| | | | T = 26, | | | T = 3, | | | T = 13, |
| **Average** | **31%** | **30%** | *p* = .46 | **20%** | **26%** | *p* = .31 | **23%** | **24%** | *p* = .94 |
| Between-word migrations | | | | | | | | | |
| YA | 5 | 4 | 0.03 | 2 | 5 | 1.03 | 3 | 2 | 0.34 |
| TA | 8 | 10 | 0.48 | 3 | 5 | 0.21 | 8 | 3 | 1.37 |
| IF | 6 | 4 | 0.53 | 2 | 5 | 1.03 | 7 | 3 | 0.7 |
| NI | 15 | 13 | 0.06 | 13 | 3 | 1.96 | 20 | 13 | 0.48 |
| IT | 5 | 0 | 1.46 | | | | | | |
| YO | 21 | 33 | 4.32* | | | | | | |
| AV | 5 | 6 | 0.19 | 7 | 7 | 0 | 8 | 12 | 0.37 |
| TW | 4 | 7 | 0.56 | 8 | 5 | 0.54 | 7 | 8 | 0.12 |
| GY | 8 | 6 | 0.68 | 8 | 7 | 0.12 | 2 | 0 | 1.01 |
| NO | 16 | 20 | 0.73 | 13 | 18 | 0.56 | 7 | 17 | 2.91^ |
| | | | T = 24, | | | T = 12.5, | | | T = 14.5, |
| **Average** | **9%** | **10%** | *p* = .38 | **7%** | **7%** | *p* = .81 | **8%** | **7%** | *p* = .64 |

^$p < .1$, *$p < .05$, **$p < .01$, ***$p < .001$

### *4.8. Do errors occur more frequently in one direction?*

Earlier studies of normal reading of word pairs in brief exposure conditions indicated that more migrations occur from the first to the second word, that is, from left to right when words are presented horizontally in English (Humphreys et al., 1990; Mozer, 1983). We are not aware of similar analyses for attentional dyslexia, but Mayall and Humphreys (2002), who tested an English-speaking patient with attentional dyslexia, reported that he had more correct responses on the right than on the left word when he read both words (but, as noted earlier, it should be mentioned that their participant showed signs of mild neglect dyslexia and this could have been the source of the increased difficulty in the left word). We thus tested whether there is a preference for a certain direction in the between-word migrations in developmental attentional dyslexia. The results might provide an answer to the question whether the preference for left-to-right migrations in normal readers of English is the result of a preferred visuo-spatial direction, irrespective of the orthography, in which case readers of Hebrew should show a tendency toward left-to-right errors as well, or whether it is a preference for migrations in the direction of reading, determined by the orthography, in which case readers of Hebrew should show more right-to-left migrations.

The results, summarized in Table 14, indicated that in reading Hebrew, our participants showed twice as many migrations from the right word to the left word (namely, from the first to the second word) as from the left word to the right word. This result suggests that the tendency for left-to-right migrations reported for normal readers of English by Mozer (1983) was a result of migrations occurring mainly from the first to the second word rather than from the left to the right word.

**Table 14 – Percentage of between-word migrations from left to right and from right to left**

| Participant | Right to left | Left to right | $\chi^2$ |
|---|---|---|---|
| YA | 62 | 38 | 4.15* |
| TA | 68 | 32 | 12.3*** |
| IF | 69 | 31 | 9*** |
| NI | 55 | 45 | 1.24 |
| IT | 62 | 38 | 2.77^ |
| YO | 70 | 30 | 27.53*** |
| AV | 73 | 27 | 11.08*** |
| TW | 39 | 61 | 2.17 |
| GY | 68 | 32 | 12.3*** |
| NO | 64 | 36 | 18.71*** |
| **Average** | **63%** | **37%** | T = 2, $p$ = .003 |

^$p$ < .1, *$p$ < .05, ***$p$ < .001

A similar analysis was conducted for vertically presented word pairs, to test whether there is a difference in migration rate from the top to the bottom word or vice versa. We analyzed this question in the single-spaced booklet of the vertically presented word pairs described in the previous section.

The results of this analysis showed no difference between the rate of migration from top to bottom and the rate of migration from bottom to top for any of the participants. On the group level, 52% (42 between-word migrations in total) of the between-word migrations were from the top to the bottom word, and 48% (38 between-word migrations) from the bottom to the top word. These rates did not differ significantly, T = 16, *p* = .42.

This finding sheds light on the source of the right-to-left errors in horizontal presentation. It indicates that they are not a general effect of memory that carries over letters from the first to the second word; rather, they are related to the reading direction typical of each language, and possibly to the patterns of attention allocation derived from the orthography.

### *4.9. Similarity: Do more errors occur when the words are more similar?*

Data from between-word migrations in skilled readers without dyslexia indicate that the more similar the words in a pair are, the more migrations occur between them (Mozer, 1983; McClelland and Mozer, 1986). To investigate whether this is also the case in (developmental) attentional dyslexia, we examined three aspects of similarity between words: *similarity in length* – whether more errors occur between words of the same length than between words that differ in length; and aspects of *shared letters* – whether more errors occur when the words share more letters, and whether certain configurations of shared letters yield more errors than others.

#### *4.9.1. Similarity: Do more errors occur when the words have the same number of letters?*

To assess the effect of similarity in length on the rate of between-word errors, we compared 30 word pairs that consisted of 3-letter words (the “same length migratable” word pairs in Table 3) with 35 word pairs in which the words differed in length (the shorter word was 2–3 letters long, the longer was 3–5 letters long, the average length was 3.12 letters – the “different length migratable” word pairs in Table 3). All word pairs in this comparison were migratable and the words in each pair had no shared letters.

##### *Results*

The results, presented in Table 15, showed no significant difference between the error rates for word pairs of the same and different lengths.

**Table 15 – Percentage errors in word pairs of the same length and of different lengths**

| Participant | Same length | Different length | $\chi^2$ |
|---|---|---|---|
| Between-word errors | | | |
| YA | 3 | 23 | 5.16* |
| TA | 17 | 29 | 1.29 |
| IF | 23 | 9 | 2.7 |
| NI | 21 | 27 | 0.21 |
| IT | 23 | 26 | 0.05 |
| YO | 53 | 63 | 0.6 |
| AV | 3 | 3 | 0.01 |
| TW | 20 | 11 | 0.91 |
| GY | 30 | 20 | 0.87 |
| NO | 50 | 46 | 0.12 |
| **Average** | **24%** | **26%** | T = 25, *p* = .42 |
| Between-word migrations | | | |
| YA | 0 | 11 | 3.65^ |
| TA | 7 | 11 | 0.44 |
| IF | 10 | 6 | 0.42 |
| NI | 5 | 9 | 0.22 |
| IT | 3 | 0 | 1.18 |
| YO | 30 | 17 | 1.5 |
| AV | 3 | 3 | 0.01 |
| TW | 0 | 3 | 0.87 |
| GY | 7 | 0 | 2.41 |
| NO | 20 | 23 | 0.08 |
| **Average** | **9%** | **8%** | T = 26, *p* = .46 |

^*p* < .1, **p* < .05

### *4.9.2. Similarity: Do more errors occur when the words have more shared letters?*

Another important dimension of similarity between words is whether or not they share letters. Shallice and McGill (1978), Mozer (1983), McClelland and Mozer (1986), and Treisman and Souther (1986) reported that in short exposure conditions, normal readers make more between-word migrations when the words in the word pair share more letters, and that when the two words share no letters, the probability for between-word migrations declines considerably.

However, the existence of shared letters can work in both directions. On the one hand, shared letters indeed increase similarity. On the other hand, shared letters give rise to invisible migrations: when the two words include the same letter in the same position, migration of this letter between the words cannot be detected and the words will be considered to be read correctly whether they actually are or not. (For example, in the word pair *word work,* the position-preserving migrations of *w*, *o*, and *r* would go undetected.)

To test how the number of shared letters affects the rate of between-word errors in developmental attentional dyslexia, we compared the number of between-word errors and between-word migrations in 3-, 4-, and 5-letter words. For the 3-letter words, we compared pairs that share no common letter, pairs that share one letter, and pairs that share two letters (30, 60, and 90 word pairs, respectively). For the 4- and 5-letter words, we compared word pairs that differ in one letter with word pairs that differ in two letters (there were 120 four-letter word pairs that differed in one letter, and 180 four-letter word pairs that differed in two letters; there were 90 five-letter word pairs that differed in one letter, and 60 five-letter word pairs that differed in two letters). All these word pairs are taken from the 725 word pairs presented in Table 3.

*Results*

The error rates for the 3-letter word pairs are presented in Table 16, and the error rates for the 4- and 5-letter word pairs are presented in Table 17. The results from the word pairs of all lengths indicated that the lowest rate of between-word errors occurred when the words included the largest number of common letters. When the pairs had all but one letter in common (i.e., when the words in the word pair differed in only one letter), the fewest errors resulted. More than one nonshared letter yielded significantly more between-word errors.

These results could be partly explained by *invisible migrations.* Whereas migrations of letters that do not exist in the neighboring word can be detected, migrations of letters that are common to the two words and appear in the same position cannot be detected. For example, for the word pair *cat bat,* migrations of the *a* or the *t* cannot be detected, so in fact only a third of the possible migrations are detected. This is in contrast to word pairs like *cat boy,* in which each migration would be detected.

Notice also that the 3-letter words that had two common letters (and only one different letter) yielded significantly fewer errors than the 3-letter words with one or no common letters even though they had the highest probability for between-word errors of the type whereby an instance of a doubled letter is omitted. Indeed, the word pairs with two common letters yielded a total of 21 such omission errors (out of 90 pairs per participant), significantly more than the word pairs with one common letter, which yielded only 6 such errors (out of 60 pairs per participant), T = 10, *p* = .04. Naturally, the word pairs with no shared letters yielded no such errors.

**Table 16 – Percentage errors in 3-letter words with two, one, or no shared letters**

| Participant | 2 common letters (1 different) | 1 common letters (2 different) | No common letters (3 different) | Comparison 1-2 common letters | Comparison 1-0 common letters | Comparison 0-2 common letters |
|---|---|---|---|---|---|---|
| Between-word errors | | | | | | |
| YA | 11 | 23 | 3 | 4* | 5.76* | 1.63 |
| TA | 13 | 27 | 17 | 4.22* | 1.12 | 0.21 |
| IF | 9 | 25 | 23 | 7.2** | 0.03 | 4.29* |
| NI | 14 | 29 | 21 | 2.91^ | 0.36 | 0.53 |
| IT | 20 | 35 | 23 | 4.21* | 1.27 | 0.15 |
| YO | 30 | 53 | 53 | 8.21*** | 0 | 5.33* |
| AV | 7 | 7 | 3 | 0 | 0.42 | 0.46 |
| TW | 8 | 17 | 20 | 2.83^ | 0.15 | 3.48^ |
| GY | 20 | 27 | 30 | 0.91 | 0.11 | 1.29 |
| NO | 22 | 48 | 50 | 11.16*** | 0.02 | 8.40*** |
| **Average** | **15%** | **29%** | **24%** | T = 0, *p* = .002 | T = 9.5, *p* = .06 | T = 7, *p* = .02 |
| Between-word migrations | | | | | | |
| YA | 4 | 12 | 0 | 3 | 3.80^ | 1.38 |
| TA | 3 | 13 | 7 | 5.3* | 0.9 | 0.63 |
| IF | 2 | 8 | 10 | 3.02^ | 0.07 | 3.41^ |
| NI | 5 | 11 | 5 | 1.17 | 0.56 | 0 |
| IT | 2 | 5 | 3 | 0.86 | 0.13 | 0 |
| YO | 4 | 23 | 30 | 12.16*** | 0.47 | 15.21*** |
| AV | 1 | 2 | 3 | 0.08 | 0.26 | 0.68 |
| TW | 0 | 7 | 0 | 6.16* | 2.09 | 0 |
| GY | 3 | 10 | 7 | 2.84^ | 0.27 | 0.63 |
| NO | 4 | 12 | 20 | 2.76^ | 1.12 | 7.13** |
| **Average** | **3%** | **10%** | **9%** | T = 0, *p* = .001 | T = 20, *p* = .25 | T = 5, *p* = .04 |

^*p* < .1, **p* < .05, ***p* < .01, ****p* < .001

**Table 17 - The effect of number of common letters on errors in 4- and 5-letter words**

| | 4-letter words | | | 5-letter words | | |
|---|---|---|---|---|---|---|
| Participant | 1 different 3 common | 2 different 2 common | $\chi^2$ | 1 different 4 common | 2 different 3 common | $\chi^2$ |
| Between-word errors | | | | | | |
| YA | 17 | 16 | 0.07 | 8 | 18 | 3.8^ |
| TA | 13 | 13 | 0.04 | 21 | 33 | 2.8^ |
| IF | 13 | 19 | 1.60 | 29 | 20 | 1.5 |
| NI | 19 | 38 | 8.81*** | 37 | 63 | 6.3** |
| IT | 33 | 37 | 0.55 | 66 | 52 | 2.89^ |
| YO | 43 | 47 | 0.44 | 44 | 80 | 18.77*** |
| AV | 8 | 9 | 0.18 | 8 | 28 | 11.32*** |
| TW | 16 | 25 | 3.61^ | 36 | 30 | 0.5 |
| GY | 27 | 32 | 1.06 | 32 | 48 | 3.94* |
| NO | 44 | 58 | 5.35* | 72 | 98 | 17.13*** |
| **Average** | **23%** | **29%** | T = 2 , *p* = .003 | **35%** | **47%** | T = 8 , *p* = .02 |
| Between-word migrations | | | | | | |
| YA | 3 | 5 | 1.17 | 2 | 8 | 3.02^ |
| TA | 0 | 6 | 6.9** | 2 | 22 | 15.12*** |
| IF | 1 | 6 | 4.55* | 0 | 10 | 9.38*** |
| NI | 6 | 15 | 4.35* | 11 | 35 | 8.36*** |
| IT | 0 | 5 | 6.19* | 1 | 13 | 9.54*** |
| YO | 5 | 14 | 6.74** | 4 | 38 | 28.1*** |
| AV | 1 | 4 | 2.59 | 2 | 17 | 10.21*** |
| TW | 3 | 5 | 0.48 | 0 | 7 | 6.16* |
| GY | 3 | 9 | 4.13* | 0 | 18 | 17.81*** |
| NO | 13 | 23 | 5.01* | 3 | 20 | 11.11*** |
| **Average** | **3%** | **9%** | T = 0 , *p* = .001 | **3%** | **19%** | T = 0, *p* = .001 |

^*p* < .1, **p* < .05, ***p* < .01, ****p* < .001

If we calculate error rates by the number of migrations out of the number of potentially visible migrations (namely, out of 1 for *cat bat*, out of 2 for *cat bit*, and out of 3 for *cat boy*), rather than out of the number of word pairs, the rate of between-word errors in 3-letter word pairs becomes similar for pairs with two shared letters and one shared letter (15% and 14.5%) and decreases for the pairs with no shared letters (8%). Even with this type of analysis, however, there were significantly more between-word migrations in 5-letter word pairs with two different letters than in 5-letter word pairs with one different letter, indicating that if anything, similarity *reduces* the number of between-word migrations for individuals with developmental attentional dyslexia.

### *4.9.3. Clustered shared letters: Do more errors occur when the shared letters are adjacent?*

One possible additional dimension of similarity is the proximity of the shared letters. It might be that a larger similar chunk would create more similarity between the words in the word pair and hence induce more between-word errors.

To test this possibility, we compared 4-letter migratable word pairs with two shared letters in which the shared letters were adjacent, with 4-letter migratable word pairs in which the two shared letters were not adjacent, but rather separated by one or two letters. This yielded 90 adjacent and 90 nonadjacent pairs (see Table 3 for the stimuli).

*Results*

**Table 18 - Percentage of between-word errors in word pairs with adjacent and nonadjacent shared letters**

| Participant | Adjacent shared letters | Nonadjacent shared letters | $\chi^2$ |
|---|---|---|---|
| Between-word errors | | | |
| YA | 13 | 18 | 0.68 |
| TA | 11 | 16 | 0.77 |
| IF | 24 | 13 | 3.63^ |
| NI | 43 | 32 | 1.57 |
| IT | 43 | 30 | 3.44^ |
| YO | 40 | 54 | 3.77^ |
| AV | 9 | 9 | 0 |
| TW | 21 | 29 | 1.45 |
| GY | 32 | 32 | 0 |
| NO | 59 | 57 | 0.09 |
| **Average** | **30%** | **29%** | T =17, *p* = .95 |
| Between-word migrations | | | |
| YA | 2 | 8 | 2.92 |
| TA | 7 | 4 | 0.42 |
| IF | 9 | 2 | 3.81^ |
| NI | 22 | 8 | 4.03* |
| IT | 7 | 3 | 1.05 |
| YO | 13 | 16 | 0.18 |
| AV | 6 | 2 | 1.34 |
| TW | 6 | 4 | 0.12 |
| GY | 9 | 10 | 0.06 |
| NO | 26 | 20 | 0.79 |
| **Average** | **11%** | **8%** | T = 13, *p* = .16 |

^*p* < .1, **p* < .05

The results, reported in Table 18, indicated that adjacency of the common letters did not affect the rate of between-word errors. The between-word error rates and the between-word migration rates were similar in the two conditions.

### *4.9.4. Do more errors occur when the shared letters are interior or exterior?*

The first and final letters are found to be the most robust letters, in priming experiments as well as in letter position dyslexia (Friedmann and Gvion, 2001, 2005; Friedmann and Rahamim, 2007; Humphreys et al., 1990; Peressotti and Grainger, 1995, 1999). Thus, words that differ in exterior letters might be more discernible than words that differ only in middle letters. Are there more between-word errors when the words share exterior letters than when they share middle letters?

To explore this question, we compared 30 migratable 4-letter word pairs in which the first and final letters differed and the middle letters were shared, with 30 migratable 4-letter word pairs that shared the first and final letters and differed in the middle letters (see Table 3 for the stimuli).

*Results*

The results, reported in Table 19, indicated that more between-word migrations occurred when the words differed in the first and final letters than when they differed in the middle letters. Interestingly, the position of the shared letters seemed to affect only migrations between words, and not the other types of between-word errors. In fact, when we examine only the omission of doubled letters, the picture is inverted – twice as many such omissions occurred when the words shared exterior letters (35) than when they shared middle letters (17). Analysis of the 35 exterior-letter omissions indicates an overwhelming tendency to omit the final letter, rather than the first: 33 of these omissions involved a doubled final letter, and only 2 the first letter. The rate of intrusions was similar in the two conditions.

In Section 4.5, we showed that the final letter is more susceptible to migration errors. This is probably the reason that more migration errors occur when the two presented words differ in their final letter, making migrations of the final letters visible. In this experiment, we found that the final letter is also the most susceptible to omission of an instance of a doubled letter, making word pairs in which the final letter of the two words is identical more susceptible to omission of the final letter. This creates the pattern of more migrations between words that differ in their final letter, and more omissions in words that have the same final letter.

**Table 19 - Percentage of between-word errors in word pairs that share exterior or middle letters**

| Participant | Shared exterior letters | Shared middle letters | $\chi^2$ |
|---|---|---|---|
| Between-word errors | | | |
| YA | 13 | 17 | 0.13 |
| TA | 13 | 13 | 0 |
| IF | 17 | 23 | 0.42 |
| NI | 28 | 37 | 0.35 |
| IT | 40 | 27 | 1.2 |
| YO | 60 | 43 | 1.67 |
| AV | 3 | 10 | 1.07 |
| TW | 30 | 13 | 2.45 |
| GY | 40 | 30 | 0.66 |
| NO | 40 | 77 | 8.3*** |
| **Average** | **28%** | **29%** | T = 19, *p* = .73 |
| Between-word migrations | | | |
| YA | 3 | 7 | 0.35 |
| TA | 3 | 13 | 1.96 |
| IF | 0 | 10 | 3.16^ |
| NI | 6 | 26 | 2.93 |
| IT | 0 | 7 | 2.07 |
| YO | 3 | 27 | 6.41* |
| AV | 0 | 10 | 3.16^ |
| TW | 3 | 0 | 1.02 |
| GY | 7 | 10 | 0.22 |
| NO | 17 | 40 | 4.02* |
| **Average** | **4%** | **15%** | T = 2, *p* = .006 |

^*p* < .1, **p* < .05, ****p* < .001

### *4.10. Does the lexicality of the migration result affect error rate?*

One of the main findings regarding within-word migrations in letter position dyslexia is the effect of migratability of the target word. When a word is migratable (namely, when letter transposition creates another existing word, as is the case for the words *beard*, *tired*, and *cloud*), more errors occur than when no lexical item results from letter migration (as in the words *computer* and *dyslexia*). This migratability effect has been attributed to the underspecification of letter position at the stage of orthographic-visual analysis (Friedmann and Rahamim, 2007). When the letters are identified but their position is underspecified, the orthographic input lexicon retrieves a word that matches the partial input it receives. Thus, when only one ordering of the letters is lexical (as is the case with nonmigratable words), the probability of correct reading is higher than when there is more than one possible lexical ordering. Does the lexicality of the response affect between-word migrations as well?

To test this question, we compared 180 four-letter word pairs for which each possible position-preserving migration creates an existing word (migratable word pairs) with 30 four-letter word pairs for which no between-word migration creates an existing word (nonmigratable word pairs). The word pairs were taken from the list of 725 word pairs (see Table 3).

To evaluate the effect of lexicality of response on the reading of *nonword* pairs, we also compared the reading of 30 pairs of nonwords for which between-word migrations yield existing words (migratable pairs) with the reading of 30 pairs of nonmigratable nonwords for which none of the possible migrations yields an existing word (nonmigratable pairs). All the nonword pairs consisted of 3-letter words whose middle letter was shared.

### *Results*

The results of this analysis, presented in Table 20, indicated that the rate of between-word migrations was higher when the migration yielded an existing word than when it did not. This pattern held both for word pairs and for nonword pairs.

**Table 20 – Percentage of between-word migrations in migratable and nonmigratable word and nonword pairs**

| | Words | | | Nonwords | | |
|---|---|---|---|---|---|---|
| Participant | Migratable pairs | Nonmigratable pairs | $\chi^2$ | Migratable pairs | Nonmigratable pairs | $X^2$ |
| Between-word migrations | | | | | | |
| YA | 5 | 0 | 1.57 | 10 | 3 | 1.07 |
| TA | 6 | 7 | 0.06 | 10 | 3 | 1.07 |
| IF | 6 | 7 | 0.06 | 0 | 10 | 3.16^ |
| NI | 15 | 5 | 1.34 | 20 | 10 | 1.18 |
| IT | 5 | 0 | 1.57 | 23 | 7 | 3.27^ |
| YO | 14 | 3 | 2.83^ | 47 | 27 | 2.58 |
| AV | 4 | 0 | 1.21 | 17 | 3 | 2.96^ |
| TW | 5 | 3 | 0.16 | 3 | 0 | 1.02 |
| GY | 9 | 3 | 1.23 | 7 | 7 | 0 |
| NO | 23 | 3 | 6.08* | 23 | 17 | 0.42 |
| **Average** | **9%** | **3%** | T = 3, *p* = .01 | **16%** | **9%** | T = 5.5, *p* = .02 |

^*p* < .1, **p* < .05

Naturally, whether or not the result of migration between words was lexical affected only migration errors. There was no difference in the rate of the other types of between-word errors between pairs of words that allow for lexical migrations and pairs that do not (20% and 22%, respectively, T = 26, *p* = .92). In nonword pairs, there were even significantly more other between word errors in the nonmigratable pairs, T = 4, *p* = .03, possibly indicating that when the pair is migratable there is a tendency to produce a migration error rather than other types of errors.

### *4.11. Is there a difference between the reading of words and the reading of nonwords?*

Some peripheral dyslexias result in different performance in reading words and nonwords. Many reports of reading in neglect dyslexia show poorer reading of nonwords than of words (Behrmann et al., 1990; Caramazza and Hillis, 1990; Haywood and Coltheart, 2001; Patterson and Wilson, 1990; Riddoch et al., 1990; Sieroff et al., 1988; Worthington, 1996), whereas reports of reading in letter position dyslexia show better reading of nonwords than of words (Friedmann and Gvion, 2001; Friedmann and Rahamim, 2007).

To compare the reading of words and nonwords in developmental attentional dyslexia, we presented a booklet with 30 pairs of 3-letter migratable nonwords whose middle letter was shared. These were compared with the 30 pairs of 3-letter migratable words that shared the middle letter (which were included in the list of 725 word pairs described in Table 3).

*Results*

The results were somewhat mixed, as shown in Table 21: three participants made significantly more between-word errors on nonword pairs than on word pairs, and one demonstrated a significant opposite tendency; the group did not show a significant difference between word and nonword pairs. An analysis of the between-word migrations alone indicated a significantly higher rate of between-word migrations in nonword pairs than in word pairs.

**Table 21 - Percentage errors in migratable words and migratable nonwords**

| Participant | Nonwords | Words | $\chi^2$ |
|---|---|---|---|
| Between-word errors | | | |
| YA | 33 | 30 | 0.08 |
| TA | 13 | 20 | 0.48 |
| IF | 0 | 27 | 9.23*** |
| NI | 23 | 25 | 0.02 |
| IT | 50 | 30 | 2.5 |
| YO | 80 | 43 | 8.53*** |
| AV | 23 | 3 | 5.19* |
| TW | 7 | 17 | 1.46 |
| GY | 33 | 23 | 0.74 |
| NO | 87 | 50 | 9.32*** |
| **Average** | **35%** | **27%** | T = 16.5, *p* = .27 |
| Between-word migrations | | | |
| YA | 10 | 23 | 1.92 |
| TA | 10 | 13 | 0.16 |
| IF | 0 | 7 | 2.07 |
| NI | 20 | 13 | 0.41 |
| IT | 23 | 3 | 5.19* |
| YO | 47 | 20 | 4.8* |
| AV | 17 | 3 | 2.96^ |
| TW | 3 | 3 | 0 |
| GY | 7 | 10 | 0.22 |
| NO | 23 | 17 | 0.42 |
| **Average** | **16%** | **11%** | T = 13, *p* = .03 |

^*p* < .1, **p* < .05, ****p* < .001

### *4.12. Are there more errors in morphological affix letters than in root letters?*

Hebrew is a Semitic language, in which words are typically created from a root and a template and often also include an inflection. Some reports on another attention-based dyslexia, neglect dyslexia, indicated that morphological affix letters are more susceptible to errors than are root letters (Reznick and Friedmann, 2009). Using pairs from the list of 725 word pairs, we tested whether attentional dyslexia shows the same pattern by examining all 4- and 5-letter word pairs in which the final letter differed between the two words, comparing words in which the final letter was unequivocally[4] morphological in both words (שברה שמרו - Sbrh Smro 'broke-feminine kept-plural') with words in which it was a root letter in both words (סגול סגור - sgol sgor 'purple closed'). This yielded 46 word pairs that end with an affix letter and 155 word pairs that end with a root letter.

*Results*

The results indicated that for some of the participants with developmental attentional dyslexia, final letters migrated significantly more often when they belonged to an affix morpheme than when they were part of the root. This was statistically significant for 3 participants, and marginally significant for one other participant. The fact that, at least for some of the participants, the between-word migrations were sensitive to the morphological status of the letter, indicates that morphological decomposition occurs very early in the course of word reading, at the stage that is also responsible for letter-to-word binding, the orthographic-visual analyzer.

**Table 22 - Percentage of between-word migrations in morphological and root letters**

| Participant | Morpheme | Root | $\chi^2$ |
|---|---|---|---|
| YA | 17 | 3 | 12.41*** |
| TA | 7 | 5 | 0.17 |
| IF | 7 | 6 | 0.06 |
| NI | 8 | 14 | 0.51 |
| IT | 11 | 4 | 3.4^ |
| YO | 39 | 14 | 10.03*** |
| AV | 20 | 5 | 8.65*** |
| TW | 3 | 5 | 0.19 |
| GY | 9 | 6 | 0.37 |
| NO | 9 | 10 | 0.04 |
| **Average** | **13%** | **7%** | T = 11, *p* = .1 |

^*p* < .1, ****p* < .001

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[4] Some words, like מגשים, MGSIM, are ambiguous, such that the final letter can be either part of an inflectional morpheme or a root letter. These words were excluded from the analysis.

## 5. Discussion

The most important outcome of this study is that attentional dyslexia exists in developmental form, and not only in acquired form. Additional results of this study refer to the specific characteristics of this dyslexia, the types of errors made, and the factors that affected the participants' reading.

The characteristics of reading in developmental attentional dyslexia that emerge from the study are remarkably similar to the characteristics of reading in acquired attentional dyslexia described in the literature (Hall et al., 2001; Mayall and Humphreys, 2002; Price and Humphreys, 1993; Saffran and Coslett, 1996; Shallice and Warrington, 1977; Warrington et al., 1993), mainly with respect to the frequent occurrence of between-word migrations that preserve the within-word position of the migrating letter.

One aim of this research was to explore in detail the types of errors individuals with developmental attentional dyslexia make. Beyond the error type that is routinely reported for attentional dyslexia, *between-word migration* (reading *wind file* as *fine wine*), we identified three additional between-word error types. One type of error, which turned out to occur frequently, accounting for 42% of the between-word errors, was the *omission of one instance* of a letter that appeared in the same position in both words (reading *sport spell* as *sort spell* or *sport sell*). These omissions can be explained by Leibniz's principle of Identity of Indiscernibles (Leibniz, 1680–1684/1969; see also 1714/1898), which states that if two objects have all properties in common, then they are identical. In our case, the two instances of *p* in the word pair *sport spell* differ solely in their ascription to the two words. Once the mechanism that ascribes a letter to a word fails, the only distinctive feature disappears, and the two letters become identical in all properties, and hence might be taken to be one. This caused the omission of one of the instances of the doubled letter. One possible explanation for the preponderance of this error type in our study is that most of the word pairs we used included several letters that appeared in the same respective positions in the two words. This kind of error has not been reported for previous cases of attentional dyslexia. In fact, Saffran and Coslett (1996) even mentioned that their participant omitted instances of double letters within words, but never omitted an instance of a doubled letter between words.

Two additional error types that characterized the reading of the participants with developmental attentional dyslexia in the current study were *buffer migration* and *intrusion*. Buffer migration is the same as the classic letter migration between words, except that the letter migrates from a previously presented word that has remained in some orthographic buffer, rather than from a word currently in the visual field. In the other error type, intrusion, the migrating letter does not substitute for a letter in the same position, but is rather added next to it. For example, intrusion of the letter *l* in the word pair *fleece feet* yields *fleece fleet.* A subtype of the intrusion error is the *elbowing* error, where the intruding letter also “elbows” the other letters toward the end of the word, causing the final letter to fall off (elbowing of the letter *l* into the word *feet* in the pair *fleece feet* results in *fleece flee*).

To assess whether these substitutions (migrations from the neighboring word or from the buffer), omissions (of a letter that existed in the same position in the other word), and additions (intrusions) were indeed between-word errors or whether they involved a letter that happened to occur in the other word by chance, we compared the rate of each of these errors that could be accounted for by the neighboring word with the rate expected by chance. The findings showed unequivocally that these errors involved a letter in the same position in the neighboring word at a rate significantly higher than expected by chance, and that participants made significantly fewer substitutions, additions, and omissions that could not be accounted for by between-word errors.

Another finding relates to the selectivity of the attentional errors. One other type of peripheral dyslexia that relates to the position of letters is letter position dyslexia. The current study indicates that these two dyslexias, letter position dyslexia, in which the encoding of letter position within words is impaired, and attentional dyslexia, in which the ascription of a letter to a word is impaired, can occur independently. The participants with developmental attentional dyslexia had severe impairment in letter-to-word binding, which was reflected in a considerable rate of between-word errors, amounting, for some of them, to more than half of the target pairs. However, their within-word position encoding was normal, as indicated by the normal rate of letter position errors within words and by the fact that their between-word migrations overwhelmingly preserved within-word position: 94% of the between-word migrations preserved the within-word position of the migrating letter. The preservation of within-word position in between-word migrations is in line with previous findings from acquired attentional dyslexia (Mayall and Humphreys, 2002; Saffran and Coslett, 1996; Shallice and Warrington, 1977). This dissociation, between impaired between-word position encoding and intact within-word position encoding, forms a double dissociation with findings from letter position dyslexia. Friedmann and Rahamim (2007) reported that at least 7 of the 11 participants with letter position dyslexia in their study did not make letter migrations between words in either vertical and horizontal presentation, although they had a severe deficit in within-word letter position encoding and made many migrations within words. This double dissociation indicates that the encoding of letter position within words and the binding of letters to words are two separate functions.

One interesting aspect of within-word position preservation sheds light on the way the position of letters within words is encoded. We found that when a final letter migrates to a word that has a different number of letters, it migrates according to its relative rather than its linear position; namely, it migrates to final position. For example, when a pair like *be lift* is presented, the incorrect reading is *be life*, with *e* migrating to the same relative position (i.e., final), rather than to the same linear position (i.e., second). This indicates that, in line with previous accounts for letter position encoding (Humphreys et al., 1990; Peressotti and Grainger, 1995, 1999), a letter's position is encoded according to its position relative to the first and final letters.

The most frequent position from which and to which letters migrated was final position, which, in Hebrew, is the leftmost letter. This is similar to the findings from normal readers of English, who made significantly more migrations of final letters. Final position was also more susceptible to omission of an instance of a doubled letter. In addition, more migrations occurred from the first to the second word when the words were presented horizontally, but no difference was found between top-to-bottom and bottom-to-top migrations in vertically presented word pairs.

Another factor that was found to affect between-word error rate was the length of the words in the word pair. Longer words yielded more between-word errors and more between-word migrations, even when the number of possible visible migrations (the number of letters not shared by the two words) remained constant. This might be explained in terms of a larger number of stimuli overloading the participant's attentional resources and causing more attentional errors.

One property of word pairs that was found to affect the rate of between-word migrations in normal readers was the similarity between the words in the pair. Normal readers were found to make more errors in more similar pairs (Mozer, 1983; Shallice and McGill, 1978). Our results, however, indicated that this factor did not affect the rate of between-word errors and between-word migrations in attentional dyslexia. Similarity in length did not increase the rate of between-word errors, nor did the number of letters shared between the two words. In fact, the more letters the two words shared, the fewer migrations occurred. We suggested that these findings can be partly explained by *invisible migrations*. Whereas it is possible to detect migrations of letters that do not exist in the neighboring word, migrations of letters that are common to the two words and appear in the same position cannot be detected. For example, for the word pair *come home*, migration of the *o*, *m*, or *e* would go undetected, so in fact only a fourth of the possible migrations can be detected. This is in contrast to word pairs that do not share letters or share fewer letters, in which more migrations could be detected. These invisible migrations might also account for the finding that more between-word migrations occurred when the words shared middle letters than when they shared exterior letters. Given that the final letter is the one that migrates the most, then when the final letter is shared, most migrations are invisible, causing a seemingly lower error rate. Notice that even if we control the number of invisible migrations, and calculate the rate of migrations only out of the number of letters that can visibly migrate, more shared letters still do not increase migration rate, in contrast with the findings from normal readers. Davis and Coltheart (2002) noticed that FL, the patient described by Mayall and Humphreys (2002), also did not show an effect of similarity, and they ascribed this difference between the patient with attentional dyslexia and the normal readers to the different source of attentional errors in the two populations: whereas the deficit in attentional dyslexia results from a deficit at the orthographic-visual analyzer, between-word migrations in the reading of unimpaired readers under short exposure conditions result from activation of two items in the orthographic input lexicon. Thus, the lack of similarity effect in our participants can also be interpreted as indicating an early deficit, at the orthographic-visual analyzer.

The lexicality of the target word pair and of the migration result did have an effect on the rate of between-word migrations. More migrations occurred between nonwords than between words, and more between-word migrations occurred when the result of migration was an existing word, both for word pairs and for nonword pairs. The lexicality effect on migrations is in line with findings from acquired attentional dyslexia: Saffran and Coslett (1996) and Hall et al. (2001) reported that their patients with attentional dyslexia made more errors in nonwords than in words, and Saffran and Coslett (1996) also reported that fewer migrations occurred when the migration result was not an existing word. Similar findings were reported for normal readers in conditions of limited exposure: they also showed lexicality effects, with more migrations between nonwords, especially when the migration result was an existing word (McClelland and Mozer, 1986; Treisman and Souther, 1986). Similar results were also reported for within-word migrations in letter position dyslexia: more within-word migrations occur when the migration creates an existing word than when the migration creates a nonword (Friedmann and Gvion, 2001; Friedmann and Rahamim, 2007).

The effect of lexicality of the erroneous response might also be responsible for attentional dyslexia being more easily detectable in Hebrew than in other languages. The morphological and orthographic structure of Hebrew creates a very dense orthographic neighborhood in which many single-letter substitutions, omissions, or additions (which can result from between-word migrations) create existing words. Furthermore, a morphological letter that migrates to the corresponding position in the other word has a better chance of creating another existing word, as it moves to a position that typically hosts morphological letters. This enhanced probability that between-word errors will create existing words might yield an elevated error rate in Hebrew compared with other languages.

Relatedly, an effect of the morphological status of the migrating letter was found for some of the participants: they made more migrations of letters that were part of the affix morpheme than of letters that belonged to the root. This finding joins a similar finding from acquired neglect dyslexia, according to which more neglect errors occur in letters that belonged to a morpheme than in root letters (Reznick and Friedmann, 2009), in indicating that some morphological decomposition occurs as early as the orthographic-visual analysis stage.

These results regarding the existence of developmental attentional dyslexia thus join a growing body of evidence for the existence of subtypes of developmental dyslexia, each showing striking similarity to the respective subtypes of acquired dyslexia. Such dyslexia subtypes have been reported for other developmental peripheral dyslexias, including developmental letter position dyslexia (Friedmann and Haddad-Hanna, in press; Friedmann and Rahamim, 2007) and developmental neglect dyslexia (Friedmann and Nachman-Katz, 2004; Nachman-Katz and Friedmann, 2007). Subtypes of central dyslexia were also found in developmental forms, including developmental surface dyslexia (Broom and Doctor 1995a; Castles et al., 2006; Castles and Coltheart, 1993, 1996; Coltheart et al., 1983; Friedmann and Lukov, 2008; Judica et al., 2002; Masterson, 2000; Temple, 1997, 2006; Valdois et al., 2003), developmental phonological dyslexia (Broom and Doctor, 1995b; Howard and Best, 1996; Temple, 1997; Temple and Marshall, 1983; Valdois et al., 2003), developmental direct dyslexia (Castels, Crichton, and Prior, this volume; Glosser et al., 1997), and developmental deep dyslexia (Stuart and Howard, 1995; Siegel, 1985; Temple, 1988, 2003). For a comprehensive survey of this literature, see Brunsdon et al. (2002); Castles et al. (1999, 2006); Castles and Coltheart (1993); and Temple (1997).

Clearly, a single deficit will not be able to account for such variety of developmental dyslexia subtypes. This variety naturally falls out from an approach ascribing each type of developmental dyslexia to a deficit in a different component of the dual-route model of reading, similarly to subtypes of acquired dyslexia (Castles et al., 2006; Castles and Coltheart, 1993; Coltheart et al., 1983; Marshall, 1984; Temple, 1997). Under such an account, developmental attentional dyslexia would be ascribed to a deficit in the orthographic-visual analysis system, in the orthographic-attentional function responsible for setting the attentional window to a single word and binding letters to words.

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